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ORIGINAL RESEARCH

Comparison of Diode Lasers in Soft Tissue Surgery using CW and Superpulsed Mode: An *in vivo* Study

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ABSTRACT

Dental soft tissue surgery by diode lasers in CW mode often causes carbonization of the tissues with following necrosis and a delay of wound healing. *In vitro* studies have already shown that superpulsed diode laser surgery has much less disadvantages for the tissues in histological approach. Purpose of this study was to investigate *in vivo*, if superpulsed mode of operation can realize an improvement for surgeon and patient in soft tissue surgery. A total of 26 patients were treated by diode lasers in different modes of operation for soft tissue surgery. Around 12 patients were treated by superpulsed Elexxion Claros diode laser: 810 nm; 10-50 W P_{peak}; 10-20 µs pulse duration; 12000-20000 Hz; 400 µm fiber. 14 patients were treated by Vision MDL-10 diode laser: 980 nm; 2.5 W; CW mode and also 400 µm fiber. Clinical treatment was documented by photos and questionnaires for patients and surgeons. Questions concerned: Carbonization, coagulation, cutting speed, pain, swelling, bleeding, need for drugs, functional reduction and fibrine layer on wounds—during treatment, directly after treatment, after 1 day, after 3 days and after 1 week. The clinical observations and the questionnaires showed in most cases signicant differences between CW mode and superpulsed diode laser treatment in surgery. It could be shown that superpulsed diode laser surgery is superior to continuous wave done treatment. Carbonization and thermal damage of the tissues can be reduced to a minimum, therefore healing is faster as in CW mode surgery. Generation of a soft tissue cut is faster and more precise. Patients have less pain in amount and time period. The need of drugs is reduced. There are less functional restrictions and there is less swelling. The advantages of superpulsed mode of operation for soft tissue diode laser surgery are evident. Continuous wave mode should no longer be implemented in diode laser surgery.

Keywords: Diode laser, Mode of operation, Laser surgery, Carbonization.

INTRODUCTION

In 1995, on the IDS, the first diode laser for dentistry was shown. It was an 810 nm diode laser with CW mode.[133] Peak power was 6 W. In 2000, a short pulsed diode laser with 810 nm, 20 W, 50 µs pulse and an average power of 2, 0-6, 7 W was introduced which showed a faster cutting and only 50% of the necrosis zone of an CW mode diode laser.[154] In 2002, the peak power reached 30 W with a pulse duration of 9 µs, a frequency of 20000 Hz and a limited average power of 10 W. Today frequencies up to 30000 Hz and peak powers of 50 W are possible. To gain a sufficient result, the peak power has to be more than 8 W in this case.[141] During the first-year of diode laser treatment in dentistry, only CW mode was possible. Several studies at that time showed that CW mode and 1 W was enough to reach a bactericidal effect on and in roots and root canals so as on implant surfaces.[13-16,51,88,106,118,120,154] Application of 3 to 4 W in CW mode led very fast to carbonization of the soft tissue; the carbonization caused higher absorption followed by a heavy thermal damage and necrosis of the tissue.[71,148,149,154] To approach better results in soft tissue treatment without much carbonization, it was necessary to interrupt the CW mode. That was done by chopping the CW mode. Pulses down to several 100 µs were realized.[141,97,145] The peak power of the pulses was in fact not higher than the peak power of the CW mode pulse, but the applied dose was decreased and the carbonization and thermal damage were reduced. A further progress were pulse durations of 9 µs, a frequency of 20000 Hz and a peak power of 50 W, which could only be generated by DPL (digital pulse technique). Using these parameters could generate a fast, sharply edged cut nearly without thermal damage of the surrounding tissue and only minimal carbonization at the cutting edges. Several studies in the recently past years have shown that short pulses with high peak powers could generate a much better result than lower powers with longer pulse duration.[17,24,26,34,35,109,151,152] Therefore, it is a major task of this study to answer the question if highly pulsed diode lasers are more suitable for soft tissue surgery than CW mode diode lasers and how the achievable results differ.

MATERIALS AND METHODS

Within a period of 5 months, 26 dental surgery treatments have been done by diode laser. Predominantly simple laser cuts, but also removal of hyperplasia and fibromas, exposure of teeth and implants, abscess incision and gingivo- and vestibuloplasty.

14 patients have been treated by Vision MDL-10 diode laser (Fig. 1):

- Vision GmbH, 30890 Göxe, Germany
- 980 nm
- 2.5 W P_{peak}

Fig. 1: Vision MDL-10 diode laser, 980 nm

- CW or 20 Hz mode
- 200 and 400 µm fiber

All procedures have been done with 2.5 W/CW mode/ 400 µm fiber

Treatment	P_{peak}	*Mode*
Single cut (4×)	2.5 W	CW
Incision abscess (1×)	2.5 W	CW
Hyperplasia (1×)	2.5 W	CW
Exposure implant (3×)	2.5 W	CW
Exposure tooth (1×)	2.5 W	CW
Fibroma (2×)	2.5 W	CW
Gingivoplasty (1×)	2.5 W	CW
Vestibuloplasty (1×)	2.5 W	CW

12 patients were treated by Elexxion Claros diode laser (Fig. 2):

- Elexxion AG, 78315 Radolfzell, Germany
- 810 nm
- 10 mW to 50 W P_{peak}
- 2.5 µs-CW pulse duration
- 200, 300, 400 and 600 µm fiber
- Digitally superpulsed (8-20000 Hz)

Fig. 2: Elexxion claros diode laser, 810 nm

All treatments have been done with the 400 µm fiber for better comparison.

Treatment	P_{peak}	*Frequency*	*Pulse duration*	P_{avg}
Single cut (3×)	50.0 W	20000 Hz	11 µs	11.0 W
Incision abscess (2×)	10.0 W	20000 Hz	20 µs	4.0 W
Hyperplasia (1×)	50.0 W	12000 Hz	10 µs	6.0 W
Frenectomy (1×)	15.0 W	20000 Hz	16 µs	4.8 W
Exposure implants (2×)	15.0 W	15000 Hz	10 µs	2.25 W
Exposure tooth (1×)	25.0 W	15000 Hz	10 µs	3.75 W
Fibroma (2×)	50.0 W	12000 Hz	10 µs	6.0 W

Both lasers have been used with fibers in contact to tissue. The fibers had been under permanent control for tidiness, because contaminated fibers decrease the applied energy, the cutting speed drops down, the treatment time prolongs and more thermal energy is given to the tissue.[145] After sufficient anesthesia, for abscess incision only superficial, in all other cases in filtration anesthesia, the treatment was done in consideration of the laser safety directions given for laser treatment of class 4 lasers.

Before, during and directly after laser treatment, photos were taken and the patients had to fill in a questionnaire. Another questionnaire had to be done by the surgeon. 1 day, 3 days, 1 week, 2 weeks and sometimes 3-month later, there was a recall to control the op sites clinically and to take some more photos. The patients had to fill in their questionnaires until 1 week after surgery. Asked subjects were intra- and postoperative pain, need of analgestic drugs, difficulties in oral hygiene or mastication. The surgeons' questionnaire asked about cutting speed of the laser, bleeding intra- and postoperative, swelling, carbonization, coagulation and fibrin layer covering. Time schedule was same as for the patients.

The diode lasers used in this study are not of the same wavelength; on the one hand there is an 810 nm diode (Elexxion Claros) on the other hand a 980 nm diode (Vision MDL-10).

According to the wavelength, it must be said that normally there is a stronger thermal effect using the 980 nm diode[72] but as shown in a recent *in vitro* study[109] from 2008, the mode of operation is much more responsible for the clinical results on soft tissue as the diode's wavelength.

RESULTS

Clinical Results

To show the visual results of a soft tissue surgery treatment by diode laser in CW and superpulsed mode, two similar cases were taken as example for all clinical cases. Treatment procedure was the same in both cases and the local sites were comparable. In both procedures, a fibroma was removed out of the inner lip. Once on both the right and the left side of the lower jaw, for better comparison, it would have been perfect if both treatments had been done on the same patient but there was no such case during the investigation period.

The visible clinical results could be described as follow:

During surgical treatment and directly after treatment, the soft tissues at the involved area were more carbonized by the Vision MDL-10 laser, which ran in CW mode; 35.71% heavy carbonization (Figs 3 to 8).

The superpulsed laser, Elexxion Claros showed sometimes carbonization too, but the amount of carbonization was much smaller, the color of the carbonized zones was more brown than black and, in a third of all cases, there was no carbonization at all (Figs 9 to 14).

Fig. 3: Fibroma before treatment with vision MDL-10

Fig. 6: One day after treatment

Fig. 4: During treatment, 980 nm 2.5 W CW mode 400 µm fiber

Fig. 7: One week after treatment

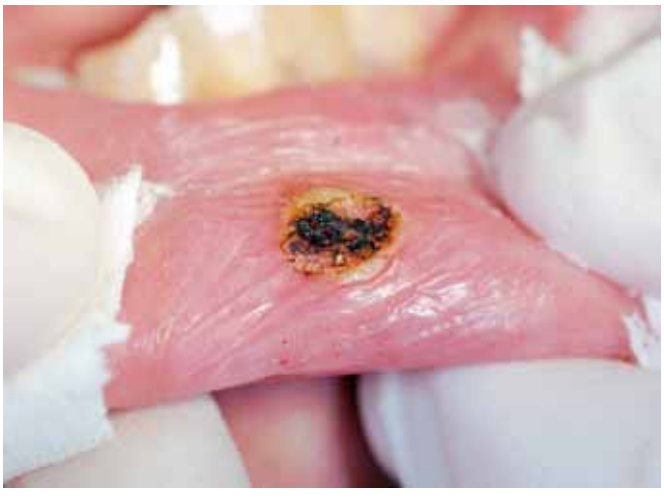

Fig. 5: Directly after treatment

Fig. 8: Three months after treatment

Fig. 9: Fibroma before treatment with Elexxion Claros

Fig. 12: One day after treatment

Fig. 10: During treatment 810 nm 50 W 12000 Hz 10 µs pulse 6 W P_{avg} 400 µm fiber

Fig. 13: One week after treatment

Fig. 11: Directly after treatment

Fig. 14: Two weeks after treatment

Carbonization	*CW mode*	*Superpulsed*
No	0%	33.33%
Little	14.29%	33.33%
Medium	50%	33.33%
Heavy	35.71%	0%

Coagulation was good with both lasers, in some situations (a patient with anticoagulant therapy—Marcumar®—INR > 2.5; not substituted) the 980 nm diode in CW mode (Vision MDL-10) had a better coagulation.

Coagulation	*CW mode*	*Superpulsed*
Little	0%	16.67%
Good	57.14%	83.33%
Very good	42.86%	0%

Both lasers did not allow common bleedings postoperatively, but in some cases, there was a little oozing bleeding; more after superpulsed laser therapy than after CW mode treatment.

Bleeding	*CW mode*	*Superpulsed*
Postoperative: No	78.57%	58.33%
Postoperative: Little	21.43%	41.67%

As the speed of cutting was very different, the superpulsed Elexxion diode laser cut much easier and faster than the Vision diode laser. The surgical procedure was done much faster by using the superpulsed laser.

Speed of cutting	*CW mode*	*Superpulsed*
Low	100%	0%
Fast	0%	25%
Very fast	0%	75%

On the following days, there was a swelling of the treated soft tissue in different sizes noticed for both laser systems.

Swelling 1 day postoperative	*CW mode*	*Superpulsed*
No swelling	28.57%	41.67%
Little swelling	64.29%	58.33%
Swelling	7.14%	0%

The swelling tendency of the superpulsed diode laser was lower and there was no swelling in more cases significantly.

Swelling 3 days postoperative	*CW mode*	*Superpulsed*
No swelling	57.14%	91.67%
Little swelling	42.86%	8.33%

After 3 days, there was only in 8.33% a little swelling left after superpulsed diode laser treatment, but in the CW mode group, 42.86% of the patients still had a recognizable swelling. One week after laser treatment, there was no swelling left in both laser groups.

Another phenomenon to be watched was the fibrin layer.

Fibrin layer 1 day postoperative	*CW mode*	*Superpulsed*
No layer	28.57%	16.67%
Small region	35.71%	50%
Mostly covered	35.71%	33.33%

Including four osteotomy cuts for CW mode and three for superpulsed mode. In total there was more fibrin layer after superpulsed treatment.

Fibrin layer 3 days postoperative	*CW mode*	*Superpulsed*
No layer	14.29%	0%
Small region	21.43%	33.33%
Mostly covered	21.43%	41.67%
Completely covered	42.86%	25%

On 3-day postoperative, the fibrin covering of the wound areas had increased in both groups.

Fibrin layer 1 week postoperative	*CW mode*	*Superpulsed*
No more layer	57.14%	66.67%
Still little layer	42.86%	33.33%

1 week postoperative, there was more reduction of fibrin layer in the superpulsed group, while the CW mode group still had a partial fibrin covered area in 42.68% of the patients.

RESULTS OF QUESTIONNAIRES

During laser treatment and directly after laser treatment, no patient felt pain or discomfort because there was anesthesia given in every treatment case.

Pain 1 day postoperative *0 = no pain* *9 = unbearable*	*CW mode*	*Superpulsed*
0	21.43%	41.67%
1	21.43%	25%
2	35.71%	25%
3	14.29%	8.33%
7	7.14%	0%

There were more patients without pain and the pain strength was on a lower level in the superpulsed group.

Pain 3 days postoperative *0 = no pain* *9 = unbearable pain*	*CW mode*	*Superpulsed*
0	71.43%	66.67%
1	21.43%	33.33%
7	7.14%	0%

Now, there were more patients without any pain in the CW mode group and also patients with very mild pain were less in the CW mode group. But, still there was a special patient with continued heavy pain.

Pain 1 week postoperative *0 = no pain* *9 = unbearable pain*	*CW mode*	*Superpulsed*
0	92.86%	100%
5	7.14%	0%

After one week, all patients in both groups were free of pain, the only exception was the special patient of the CW mode

group. For better understanding, it has to be said that the mentioned patient was very algesic; a vestibuloplasty had been done and the extended denture was incorporated directly after laser treatment, so the healing was inhibited for a certain degree and the denture was grinding on the wound area all the time.

Analgesic drugs needed	*CW mode*	*Superpulsed*
No	57.14%	66.67%
Yes, 1 day	35.71%	25%
Yes, 3 days	0%	8.33%
Yes, 1 week	7.14%	0%

The need for analgesic drugs was higher in the CW mode group, 42.85%. Need for medication in the superpulsed group: 33.33%. The above-mentioned special patient needed a week of medication.

Reduced Masticatory or Lingual Function

Reduced function	*CW mode*	*Superpulsed*
No	0%	16.67%
1 day	28.57%	33.33%
3 days	57.14%	50%
1 week	7.14%	0%
More than 1 week	7.14%	0%

The influence of the laser treatment on functional aspects, e.g. mastication lasted in average 3 days. In the CW mode group even longer in two cases. Only in the superpulsed group, 16.67% were without any functional limitations.

Difficulties in oral hygiene	*CW mode*	*Superpulsed*
No	0%	8.33%
1 day	35.71%	41.67%
3 days	57.14%	50%
1 week	0%	0%
More than 1 week	7.14%	0%

Nearly, the same result for difficulties in oral hygiene. Average was as well 3 days. Even there were patients without difficulties in the superpulsed group (8.33%).

DISCUSSION

Discussing the results from the study, one certain thing has to be remembered. The CW mode laser (Vision MDL-10) had always been used with 2.5 W and CW mode.

So, peak and average power had always be the same in every procedure.That is the main difference to the superpulsed laser (Elexxion Claros) which had been used with different parameters; 10 to 50 W peak power; 2.25 to 11.00 W average power; 12000 to 20000 Hz; 10 to 20 µs pulse duration.

The precise treatment parameters of the Elexxion Claros laser were:

P_{peak}	P_{avg}	*Frequency*	*Pulse duration*
6 × 50 W	3 × 11.00 W	6 × 20000 Hz	6 × 10 µs
1 × 25 W	3 × 6.00 W	3 × 15000 Hz	3 × 11 µs
3 × 15 W	1 × 4.80 W	3 × 12000 Hz	1 × 16 µs
2 × 10 W	2 × 4.00 W		2 × 20 µs
	1 × 3.75 W		
	2 × 2.25 W		
ϕ32.5 W	ϕ6.00 W	ϕ16750 Hz	ϕ12.42 µs

The used peak power was sometimes 20 times higher than the peak power of the CW mode laser; and even the average power was more than double (2.4 times higher). Regarding to this, there was no doubt that the Elexxion laser would cut much easier and faster than the Vision laser. Thanks to the superpulsed mode of operation, there was less carbonization and less damage of the adjacent tissue which had been proven histologically *in vitro* by Bach et al, in 2008.[109] Peak power was nearly the same as in this study, average power 1.67 times higher as in this study and the average frequency also higher. Still the results were much better for the superpulsed laser than for the CW mode laser. Maiorana and Salina[151] did a clinical study with a superpulsed laser on three patients in 2006. The parameters were similar to this study, only the peak power was signicantly lower and the number of patients was only three. But the summary of both studies corresponds with the results achieved in this study. The results out of this comparative *in vivo* study are sometimes very signicant, so in case of the cutting speed. The use of high powers, short pulse durations and high frequencies offered a high speed for cutting and a deeper cut as it did in CW mode. The margins of the cut were more defined and more straight using superpulsed mode. This was already described several times in literature.[26,34,145]

When using the CW diode laser, the cut was flattish and the cutting speed was low. Certainly, the low peak power of the Vision MDL-10 was one great inhibition factor for speed. Another one may have been the wavelength of 980 nm. The 810 nm diode has less penetration into the depth, a lower absorption in water, a lower absorption in HbO_2 and nearly the same absorption in Hb as a 980 nm diode. The 980 nm diode creates more thermal energy at the surface. The zone of necrosis is larger and it is more dangerous for cutting. Surprisingly, Bach et al[109] could prove (2008) in *in vitro* studies that there was no difference from the histological point of view between 810 nm and 980 nm diode lasers, when both are used in the same mode of operation.

If we assume that Bach's results were correct and we neglect the difference between *in vitro* and *in vivo* studies, we can conclude together with the attained results from this study that superpulsed mode of operation will lead to faster cutting speed and a more precise cut with less tissue damage.

There are a lot more parameters apart from the wavelength, power, frequency, pulse duration, fiber diameter and mode of operation that will influence the cutting ability, so as, e.g. kind of tissue, pigmentation, race, blood circulation in tissue, applied

dose, treatment time, etc. but these parameters are of subsidiary relevance in this study.

The above shown reference cases are done with patients of the same race and same gender. The soft tissue region was the same, both patients with similar pigmentation.

The treated sites were mirror-inverted at the inner lip of the lower jaw. Next point to view is the carbonization of the tissue. If there is a lot of carbonization, the destruction of the surrounding tissue is large.[37,45,71,109]

Carbonization is changing the absorption of the treated tissue; it is increasing due to the dark color which absorbs the diode laser light much better than light colors do.

This means there is more thermal energy applied in the surface and necrosis of the adjacent structures is created. As we can see from the study, the changing of parameters could influence the degree of carbonization and coagulation; which had already been described in literature.[145] A much smaller degree of carbonization and destruction is described when using pulsed instead of CW mode.[24,26,34,35,41,61,62,109,145,151] This can be consolidated by the results achieved here. The total amount of carbonization was much higher in the CW mode group. The fiber diameter is another factor for the applied dose and perhaps the carbonization could have been decreased by using a larger fiber; but for better comparison both lasers were used with 400 µm fibers.

Next aspect to discuss is the coagulation ability of both modes of operation. In literature, the coagulation efficiency is described as good[17,30,42,67,68,131,145] to very good[7,37,51,72,142] for CW mode.

For superpulsed mode, the coagulation mentioned is very good[17,35,143] and good with minimal bleeding.[34]

During treatment, the coagulation was very good in 42.86% of the treated patients and good in 57.14%. For superpulsed, there was no very good coagulation, but 83.33% good and 16.67% little coagulation which meant that a few patients had a minimal bleeding.

In CW mode there was none. This might have been a derivation of the higher thermal damage of the CW mode laser. The blood vessels were sealed better by the influence of the larger amount of thermal energy delivered by the CW mode of operation. Swelling of the wound area and adjacent tissue 1 day after surgery was significantly less in the superpulsed group, 41.67% with no swelling. Only 28.57% with no swelling in the CW group. The size of swelling did not differ much in both groups. Three days after treatment there were already 91.67% of the patients free of swelling in the superpulsed group. Only 57.14% of the CW mode group which is a significant difference. The reason for this could be the degree of tissue damage caused by laser irradiaton. Regarding to the lower degree of carbonization and thermal damage in the superpulsed group, it was explainable that there was less swelling.

The literature review showed different kinds of results which varied from no swelling[17,72] to little swelling[26,37,41,46,142,145,151] for both kinds of lasers. During and directly after laser treatment, there was no pain because all patients had been given local anesthesia before surgery. Surgical treatment with a diode laser always requires anesthesia, because the thermal energy applied always generates pain. In literature classifications as mild pain,[37] less pain,[26,34,145] reduced pain,[30,41,46,72,142,145] minimal pain[151] and no pain[17] are found and all authors agree that the degree of pain is reduced after laser treatment in comparison to classical treatment by scalpel.

Looking to the results of the questionnaire, a recognizable larger percentage of patients had no pain 1 day postoperative in the superpulsed group: 41.67%. Only 21.43% in the CW group had no pain. Nearly double of the patients in the superpulsed group were painfree. Saaleh et al[37] noticed an average of 3 days of pain for all patients in their study after CW mode treatment.

After laser treatment, the patients had been supplied by an analgesic drug, ibuprofen 400 mg, 42.85% of the patients in the CW group needed medication, but only 33.33% of the patients in the superpulsed group with a high percentage, only 1 day. That corresponded to the findings for pain that have been done before. In general, we can say that the pain sensation was less in the superpulsed group. In order to the trauma set during laser treatment there was a functional reduction for masticatory and/or lingually function in both groups. In the CW group, every patient was affected. In the superpulsed group at least 16.67% of the patients had no functional limitations. 50 to 57.14% of the patients were handicapped for 3 days in both groups. That corresponded once again to the study of Saaleh et al[37] who described a 3-day period of painful mastication and speech after CW mode treatment. Nearly the same results for oral hygiene. In average 3 days of limitation, but this time only 8.33% of the patients in the superpulsed group without any difficulties, in the CW group, all patients with difficulties. The observed results regarding the fibrin layer differed from the normally seen wound healing after classical treatment by scalpel. The faster fibrin layer is removed, the faster wound healing is in progress. In this study, 26 patients were treated, but seven of them only by simple laser cut for osteotomy. The cut was sutured afterwards, so there was primary wound healing and no visible fibrin layer could be seen. The first day no fibrin layer was seen on the wounds in 28.57% of the CW group and only 16.67% of the superpulsed group. After 3 days, all wounds (100%) were covered with fibrin in the superpulsed group: 41.67% were mostly covered; 33.33% partially and 25% completely. In the CW group, already 42.86% were completely covered; 21.43% mostly; 21.43% partially, but still 14.29% were not covered yet. So far fibrin layer building was faster and more complete in the superpulsed group. In comparison to healing after conventional surgical treatment, there was a delay of healing time, because fibrin layer building started later and needed more time to cover the wounds. Delayed wound healing after surgical diode laser treatment has already been described in literature[26,31,32] and,

as we could see from the results above, the wound healing of the CW group started later and lasted even longer as the prolonged wound healing of the superpulsed group. Superpulsed diode laser treatment did not cause much carbonization, but there was coagulation as well, which meant applied thermal energy on the blood vessels and cells; causing damage and therefore delayed healing.

In summary, we can say that superpulsed diode laser treatment is contrary to CW mode diode laser treatment much more gentle for the tissue (less damage, quicker healing), more comfortable for the patient (less pain and swelling) and an improvement for the surgeon (more precise and deeper cut, less burnt smell, shorter treatment time). Only the coagulation ability of the superpulsed diode laser seems to be minimal inferior of the CW mode diode laser. In combination with the findings of the Bach study[109] and the case reports of Maiorana and Salina,[151] we can conclude that superpulsed diode lasers should be the state-of-art treatment, nowadays, if there is spoken about surgical diode laser treatment. Of course these are only two further studies and the results have to be reconfirmed by various studies with a larger amount of patients but the direction to go is clearly given.

CONCLUSION

Clinical *in vitro* and *in vivo* studies have shown that soft tissue surgery done by superpulsed diode lasers is more reasonable as doing the same procedures by CW mode diode lasers. Carbonization and thermal damage of the adjacent tissue can be reduced to a minimum, the soft tissue cut can be generated faster, the cut is more precise. Because of the lower amount of tissue destruction, the healing is faster as in CW mode. It is more comfortable for the patients regarding to the postoperative pain and swelling, the patients will need less drugs and the functional abilities are not reduced as much as in continuous wave mode. The advantages of the superpulsed diode lasers in soft tissue surgery are evident and with the meanwhile achieved peak powers, the very short pulse duration and the high frequency surgical treatment can be improved and probably the range of treatment can be expanded.

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